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An analysis of time restraints for farm planning

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AN ANALYSIS OF TIME RESTRAINTS FOR FARM PLANNING

by

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INTRODUCTION

Labor has become an increasingly important problem in farm planning. A resource which was once considered a surplus resource, hired labor is now in short supply and very much in demand in agricultural communities. Improved communication, travel, and education of the people have caused many farm workers to leave farming for occupations in other industries.

This reduction of the farm labor force has caused farm managers and operators to re-examine their farming operations in an effort to adjust to this situation. Changes have been made and further changes will be forthcoming in input and output mixes in an attempt to meet the labor shortage problem. Mechanization of routine farm chores, larger and more powerful field machines, minimum tillage, and liquid manure systems are all attempts to solve this shortage of labor problem.

Of prime importance to farm planners when attacking the labor problems are the time restraints within which he has to work. Two time restraints can be identified as being important. They are (1) The total number of hours available for productive work on farming enterprises. This consists of total waking hours minus such items as time taken for meals, travel time between parcels of land, time taken for repairs and maintenance, record keeping, and others which reduce the actual productive time restraint. (2) The number of hours available at certain times of the cropping season for field operations.

involved here is an estimate of the restraint imposed by weather and field conditions on the cropping activities. It is these two aspects of farm labor which will be examined in this thesis.

Crop acres farmed, the cropping system followed and machinery investment on a farm are functions of the amount of time available for field work. The total farm size, types and numbers of livestock raised, and other characteristics on the total amount of time the farm operator has to invest in his farm business.

It is relatively easy to define the amount of land available for farming. Likewise the amount of capital and capital goods such as machinery, equipment and supplies can be routinely inventoried for use in farm planning. This inventory process is not so easy for the labor resources of the farm. The actual count of the labor force is not difficult but to define the actual number of hours this labor force will be able to invest in the farm business is quite another matter. Such things as hired labor availability, illness and disability of farm workers, and off farm demands for the operators time, all affect the amount of work forthcoming from the labor force.

It was decided to select one area within Iowa with the expectation that the method developed could later be used to define time restrictions in other locations. A farm in Monona County in west central Iowa was chosen upon which to concentrate efforts to develop time restraints and coefficients. The operator agreed to keep a log of work time for one full year. From this data and from data developed from Weather Bureau records time restrictions and coefficients were developed.

In the past farm planning models time restrictions have been defined in a crude manner. This is unfortunate since the method of analysis can be made sufficiently refined and sophisticated to accommodate a more detailed analysis. Time restrictions for field operations have been no better than guesses in many cases and simple averages of time devoted to field operations during some past period in others. In this thesis weather and agronomic data are analyzed in an effort to demonstrate a method of defining time restrictions which removes part of the ambiguity.

The objectives may be summarized briefly as follows:

1. To examine the importance of accurate field time restrictions in linear programming applications to farm planning.

2. To develop methods to define accurate and reliable time restraints for use in linear programming models.

3. To develop a linear programming model with which such time restrictions can be used.

The thesis proceeds along the following outline:

1. A review of linear programming procedures and applications.

2. Definition of the field time restrictions.

3. Examination of how the newly defined restraint can be used to make planning models more meaningful.

METHOD OF ANALYSIS

Linear programming has come to be an accepted and useful method of farm planning. It has survived its infancy and is at present an accurate method of arriving at solutions to farm planning problems. The application of programming has been aided greatly by the developments in electronic computers. A computer when used in this way is merely a fast and accurate calculator able to do many arithmetic calculations in a short period.

Linear programming involves the use of input-output coefficents to define the resource requirements of alternative production activities. Defining coefficients accurately is a major portion of the job of applying programming as a planning tool. If these coefficients are not accurately defined the solution forthcoming will not have the desired degree of accuracy.

A second set of information necessary for building a model is the resource restrictions. The number of acres available, the machine resources available for use in the productive enterprises on the farm, the amount of capital available for investment, and the one in which this study is most interested, the amount of time available during certain seasons to perform critical field operation.

Linear programming is essentially a budgeting procedure using electronic computers to accomplish the many arithmetic computations. The use of computers allows the programmer to consider many more alternative enterprises, known as activities in programming language, and to do so more quickly, more cheaply, and with much greater accuracy than with the budgeting technique.

Two important economic concepts are inherent in linear programming procedures. These are marginal productivity analysis and opportunity cost.

Marginal Productivity Analysis

Changes in solutions are made in a problem until the marginal productivity of every input is equated. In theory with unlimited quantities of inputs the amount of an input used for production would be increased until Equation 1[1] is fulfilled.

$$MPP_a P_x = P_a \qquad (1)$$

In most cases, however, with real farm situations the amount of one or more inputs is limited preventing Equation 1 from achieving equality. In this case, Equation 2 must be satisfied to achieve maximum profit given the restrictions.

$$MPP_a P_x = MPP_b P_x = \ldots\ldots = MPP_n P_x \qquad (2)$$

A second condition for maximum profit is that the marginal productivity of a given input be equated among the various activities for which it is used. This condition is shown in Equation 3.

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[1] MPP_a = Marginal physical product of input a.
P_x = Price of output x.
P_a = Price of input a.

$$MPP_{ax}P_x = MPP_{ay}P_y = MPP_{az}P_z \qquad (3)$$

With linear programming Equations 2 and 3 are fulfilled.

Opportunity Cost Principle

The basis for the changes in the solutions of linear programming problems is the opportunity cost principle. For example, what is the value of units of activities sacrificed relative to the value of the increase in the level of other activities when shifting one unit of an input from one activity to the other? If the value of the production sacrificed is less than the value of the potential production gain then profit can be increased by making the change. Equation 4 indicates this situation.

$$MPP_{ax}P_x < MPP_{ay}P_y \qquad (4)$$

Linear programming is efficient in applying the opportunity costs principle in that a computer can calculate returns from many resource combinations and compare them to find the mix of activity levels which will add the most to profit.

Objective Function

In order to make any decision regarding resource allocation, activity choice, activity level, and expected net income one must decide first on an objective function. Many choices are available.[2] In most cases involving farm planning the

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[2]Several such choices are a minimum net income, maximum leisure time, security, maximum gross income, minimum amount of labor, no borrowed capital, and many others.

objective function is that of maximizing net income subject to a specified set of restraints.

This objective function can be written algebraically as in Equation 5.

$$Z_j = P_i X_{ij} - C_i X_{ij} \tag{5}$$

Where P_i=per unit price of output i, i=1 . . . . . n outputs. X_{ij}=number of units of output i in plan j, i=1 . . n outputs. j=1 . . m. plans. C_i=per unit cost of output i, i-1 . . . . . n outputs. Z_j=net profit of plan j, j=1 . . . . . m plans.

Geometric Representation

Starting with the simple case of two outputs and one input a production possibility line, or curve, can be drawn as in Figure 1. Assume (1) the input land is restricted to 100 acres (2) activities are corn and soybean production (3) expected yields are 50 bushel per acre for corn and 25 bushel per acre for soybeans, then Equation 6 can be defined as follows, where x indicates the production of corn in bushels and y indicates the production of soybeans in bushels.

$$.02\,x + .04\,y = 100 \tag{6}$$

This indicates that an input of .02 acres is required to produce one bushel of x or corn and .04 acres is required to produce one bushel of y or soybeans. Subtracting .04 y from each side and dividing .02 gives Equation 7 expressing the production of corn as a function of the production of soybeans.

$$x = 5000 - 2y \tag{7}$$

Similarly the production of soybeans can be expressed as a function of the production of corn as follows in Equation 8.

$$y = 2500 - .5x \tag{8}$$

Thus when the production of soybeans is zero, or when no land is used in the production of soybeans, the production of corn is 5000 bushels. Also when the production of corn is zero the production of soybeans is 2500 bushel. Any point between these extremes is a feasible production possibility as shown by line AB in Figure 1.

The coefficient of .5 for x in Equation 8 is the ratio $\frac{\text{land requirement per unit of corn}}{\text{land requirement per unit of soybeans}}$ or $\frac{.02}{.04} = .5$. It is also the marginal rate of substitution of soybeans for corn. The MRS indicates the amount of soybeans which must be sacrificed in order to obtain a one unit increase in the production of corn. Since Equation 7 is a linear relationship the coefficient 2 is also the slope of the production possibility line.

In the planning procedure there are an infinite number of feasible points of production. Any point on or below line AB in Figure 1 is representative of one of these. The points on line AB represent the points of maximum production using the optimum management and technology available to the producer. Which of these is economically optimum depends on the relative prices of the two outputs corn and soybeans. Using conventional economics of comparing the ratio $\frac{\text{change in production of soybeans}}{\text{one unit change in the production}}$

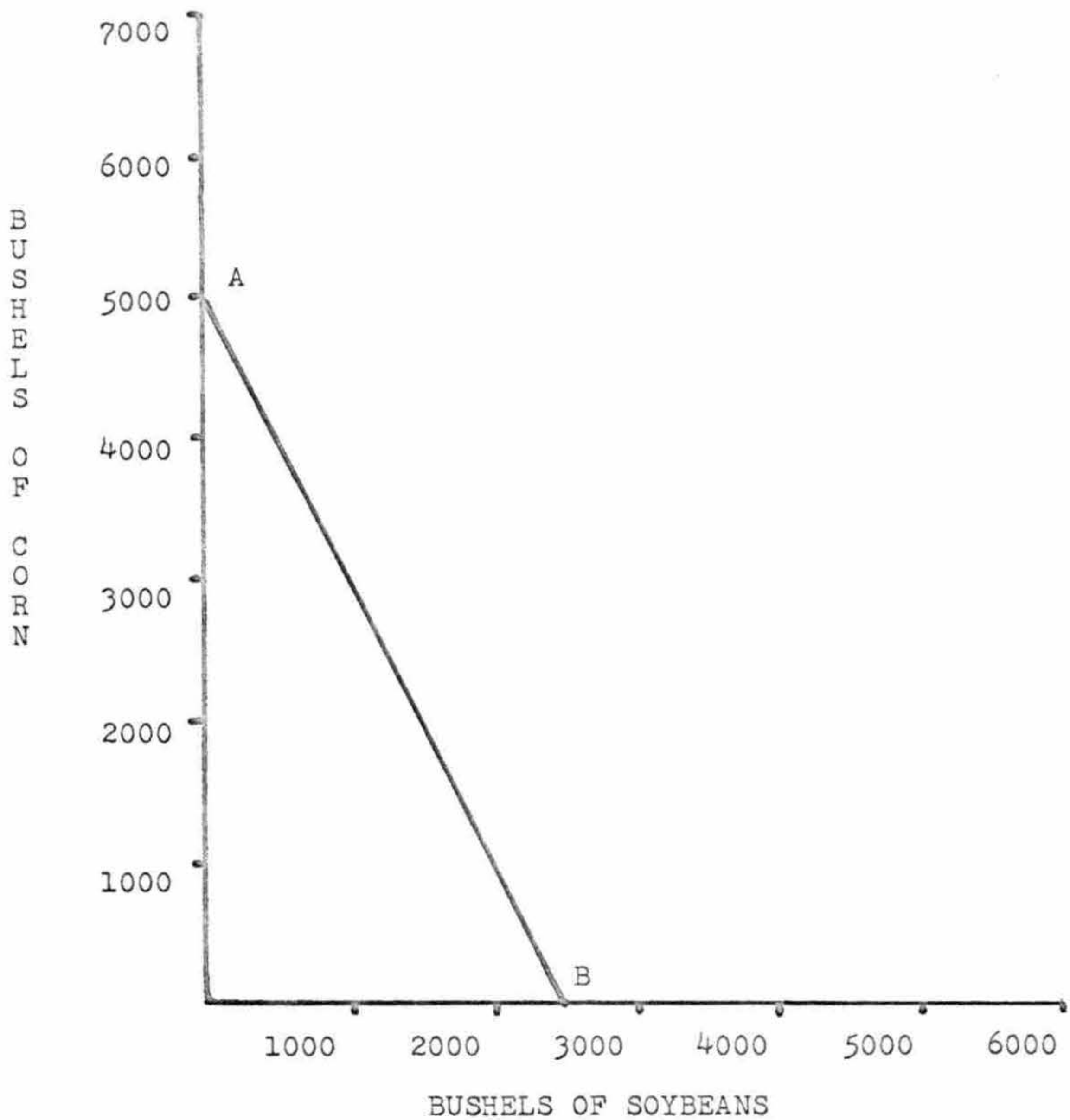

Figure 1. Production restrictions with one input

of corn or the marginal rate of substitution[3] of soybeans for corn with price ratio $\frac{\text{price of corn}}{\text{price of soybeans}}$.[4] If MRS > PR then an increase in the production of corn will add to profits. Figure 2 shows a price ratio line with slope of $\frac{Pc}{Psb}$=PR. This line represents an isorevenue line since any point on the line indicates a combination of corn and soybeans which will provide an equal level of income. The further the isorevenue curve is from the origin of the graph the higher revenue it represents. This is intuitive since at a given set of prices as the amount of bushels sold increase the revenue will also increase.

When Figure 2 is superimposed over Figure 1 or when MRS is compared with the PR as in Figure 3 the maximum profit point can be found. The isorevenue line CD can be moved closer or further from the origin until the furthest, highest revenue, point is found. This is where the isorevenue line cannot be moved further from the origin without going beyond the range of possible production. In this case the maximum income is at point AC as in Figure 4.

Actually with linear lines as shown in Figure 4 there are only two points to consider for maximum profits these are points A and B. If the slope of the isorevenue line is greater than the slope of the isoresource line (MRS < PR) then the rational plan is to increase soybean production to its maximum at B and

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[3]Abbreviated MRS for the balance of this paper.

[4]Abbreviated PR for the balance of this paper.

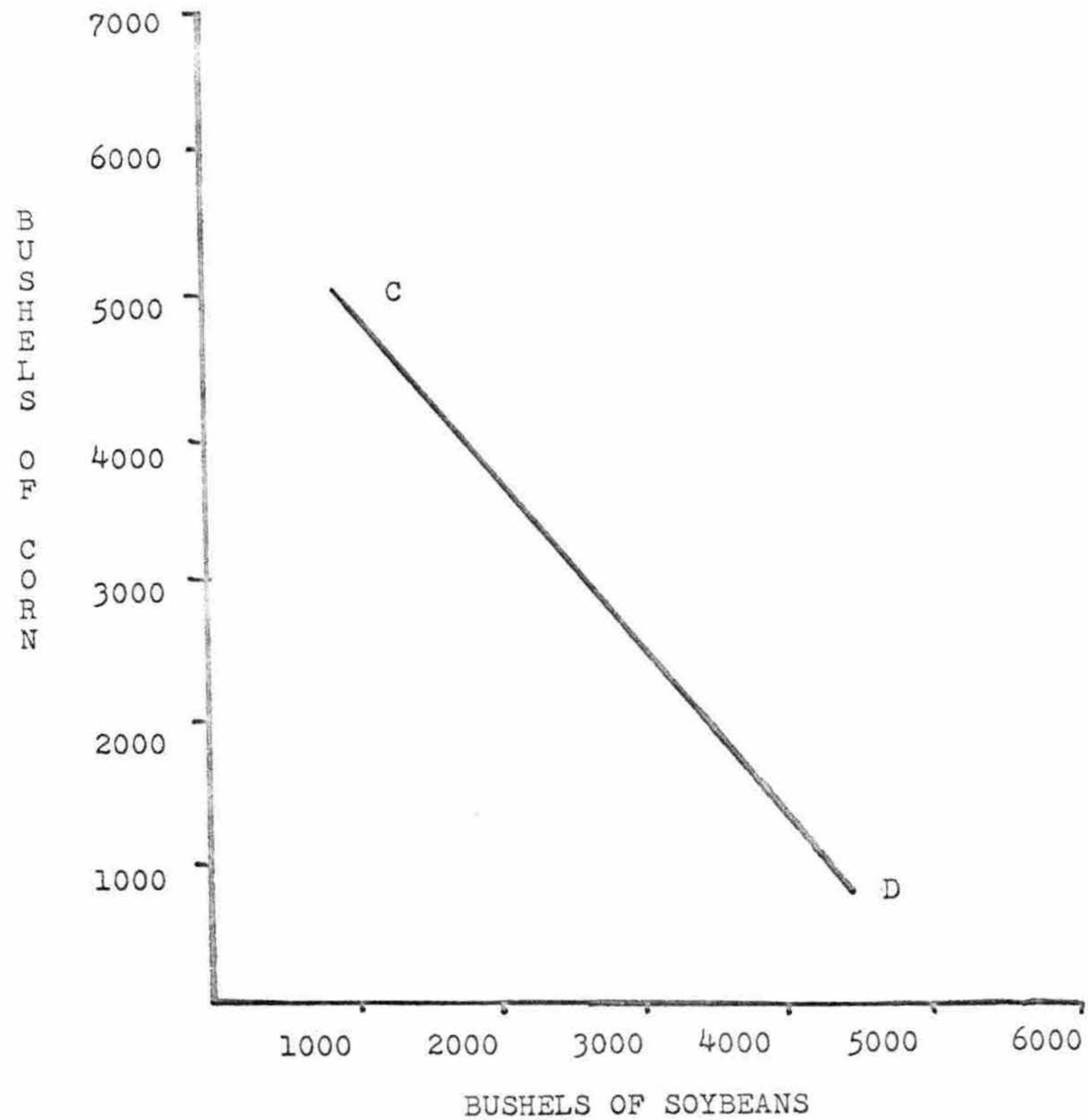

Figure 2. Isorevenue curve

reduce corn production to zero. If on the other hand the slope of the isorevenue line is less than the slope of the isoresource line (MRS>PR) then an increase in corn production to its maximum at A and a reduction in soybean production is the optimum plan. Only when the slopes of these two lines are equal (MRS=PR) is the solution indeterminate. For example, production will be equally profitable at any point on the line.

When this analysis is expanded to consider more than one input such as labor, capital, or any of those used in the production of corn and soybeans the production possibility curve takes on a different shape. Figure 5 shows a case where three restricting inputs are considered land, planting labor, and capital. Line AB again represents the land restriction. CD represents planting labor indicating that labor is available to raise 4000 bushels of corn or 4000 bushels of soybeans or any combination on the line. Line EF represents the capital restriction indicating that 7000 bushels of corn or 2000 bushels of soybeans or any combination represented by the line can be produced with the capital available. As can be noted the lines intersect defining contradicting production possibility curves. Line CD defines a point of less corn production than lines AB or EF when only corn is to be produced. Likewise, with all inputs devoted to soybeans, line EF restricts production to 2000 bushels even though the other inputs would allow a greater production. The actual production possibility curve in this case is a line made up of the most restrictive inputs. This line is shown in Figure 6. As more inputs are considered the curve

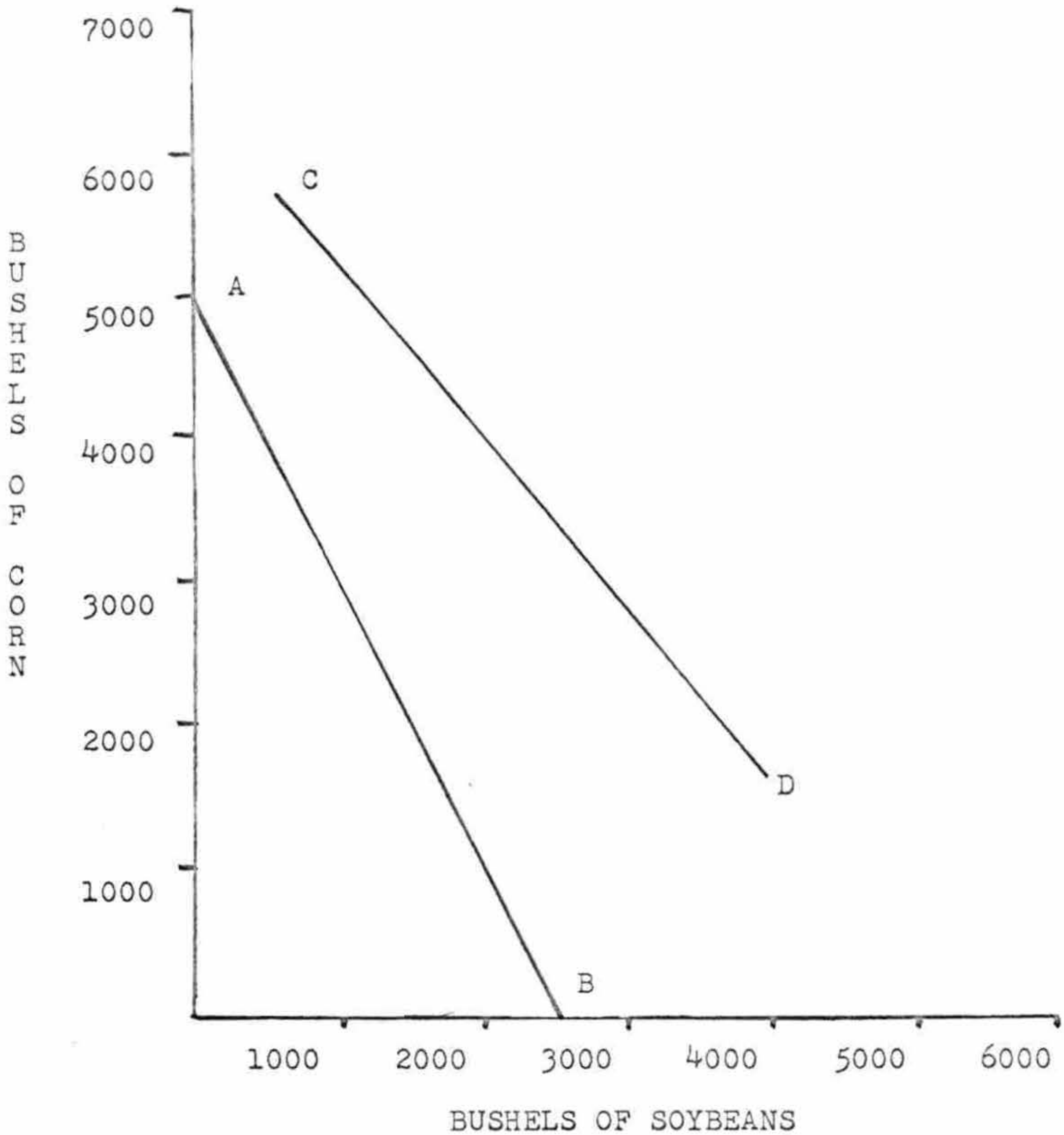

Figure 3. Production possibility curve plotted with isorevenue curve

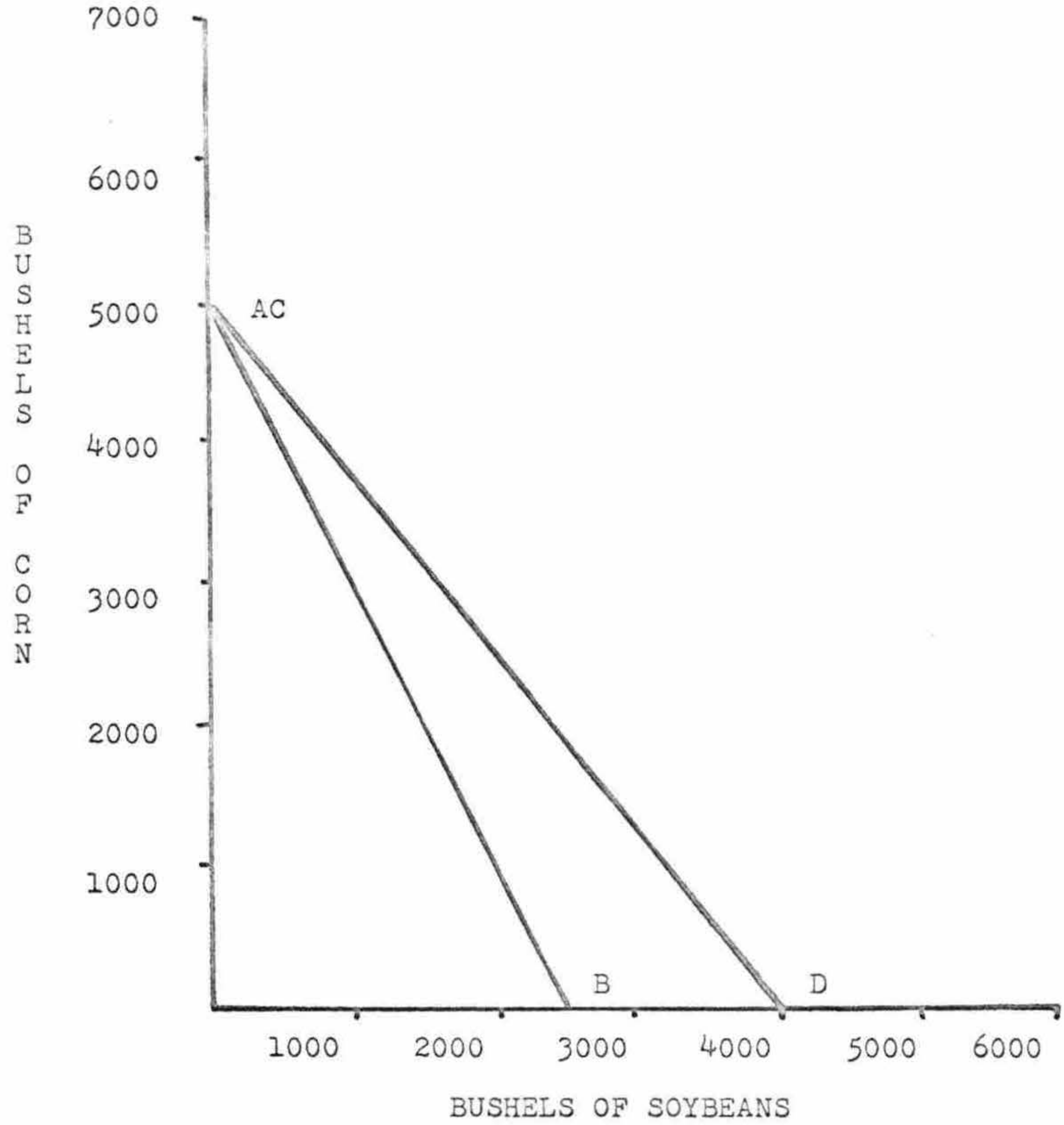

Figure 4. Determination of production quantities one input case

approaches a smooth curve such as that of the traditional production possibility curve.

As more inflections in the curve appear such as points B and C in Figure 6 the number of possible solutions increases.

In Figure 7 the price ratio line LM is equated with the MRS indicated by the production possibility curve AD at point B. This is the optimum point of production since at any other inflection point income would be less.

This then is briefly what the linear programming procedure does as it advances toward a solution. Each inflection point on the production possibility curve is compared with the next one to determine which represents a higher income. When a point is reached which has no other point representing greater income the solution is achieved. The electronic computers using this procedure have the ability to make many of these comparisons accurately and quickly.

Assumption of Linear Programming

There are four assumptions which are inherent in linear programming and must be realized by one who is using the procedure or by those interpreting the results. These are linearity, additivity, divisibility and finiteness.

Linearity

As the name linear programming implies all activities considered in a program are linear in nature. In other words, no economies or diseconomies of scale appear. The n^{th} unit

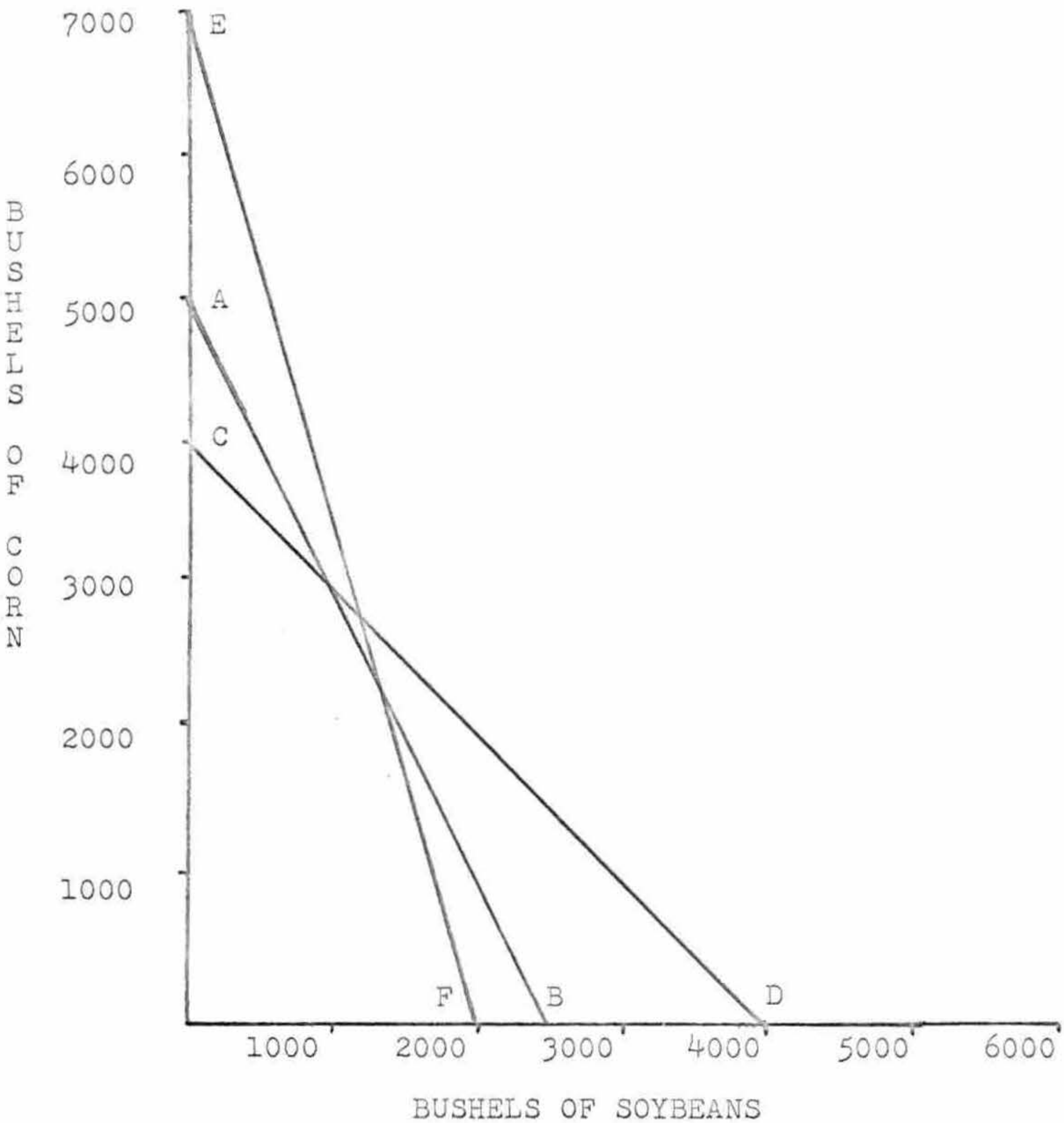

Figure 5. Production restrictions with three inputs

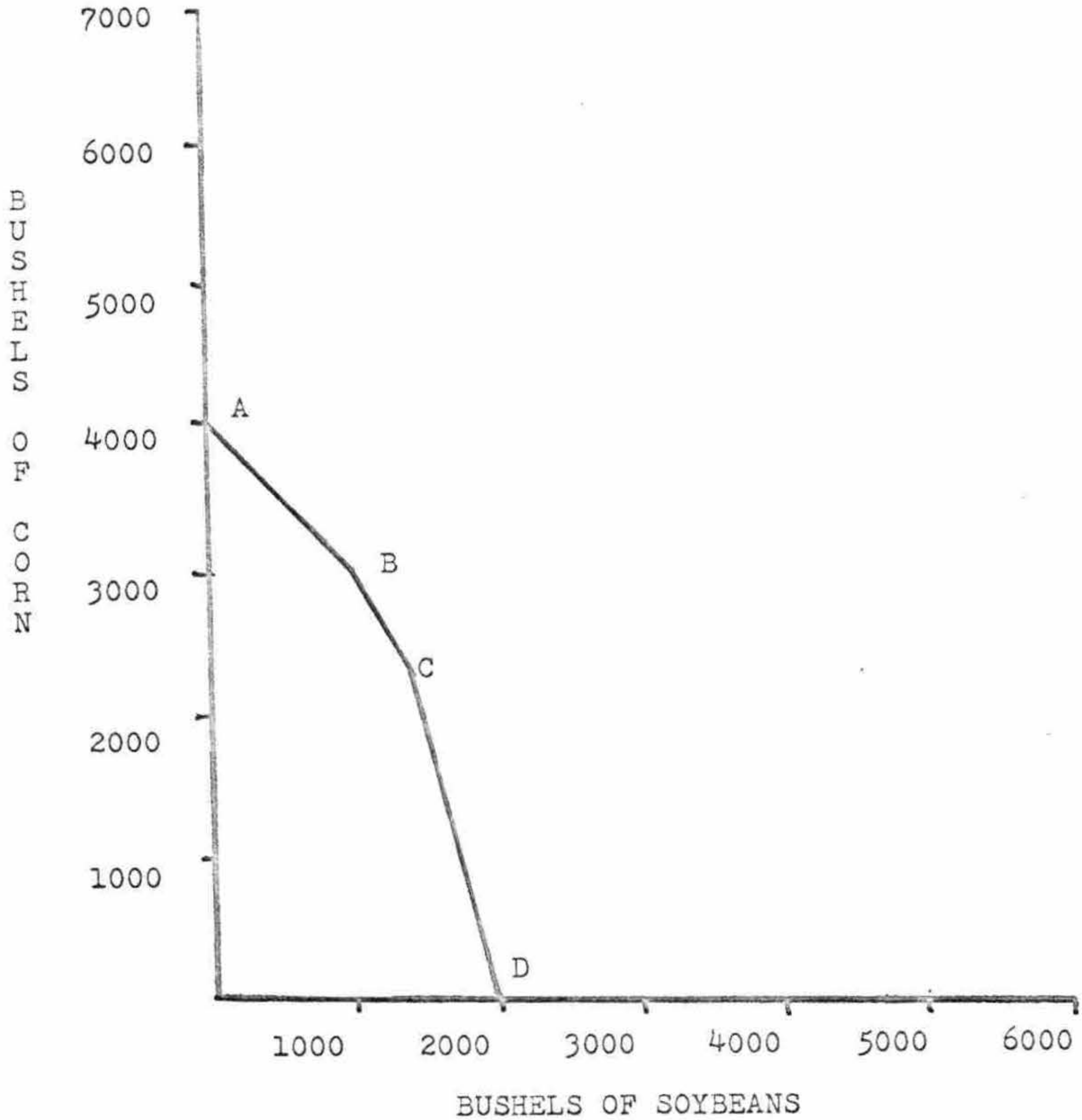

Figure 6. Production possibility curve

of the activity returns exactly the same income and requires the same inputs as the first unit. This is a very restricting assumption since few agricultural activities are of this nature. This can be overcome however by increasing the number of activities. One method is to break down the production function into several segments which approach linearity. An example would be to develop one activity for a hog enterprise with 0 to 10 sows per year and another activity with 11 to 25 sows per year. Each would have its unique set of coefficients. A second method is to develop different activities for the various amounts of inputs. Fertilizer application on corn would serve as an example. One activity could call for low levels of fertilizer application and a second for medium levels. Each would require approximately the same inputs with the exception of fertilizer. (Each would however have a unique net price.)

Additivity

The activities which appear in the solution are additive both in amounts of inputs used and in returns. There is no provision for interaction between activities. For example, an activity producing alfalfa has no effect, beneficial or harmful, upon an activity which raises corn. If any interaction is to be considered it must be within a single activity. In the corn-alfalfa example interaction can be introduced with a

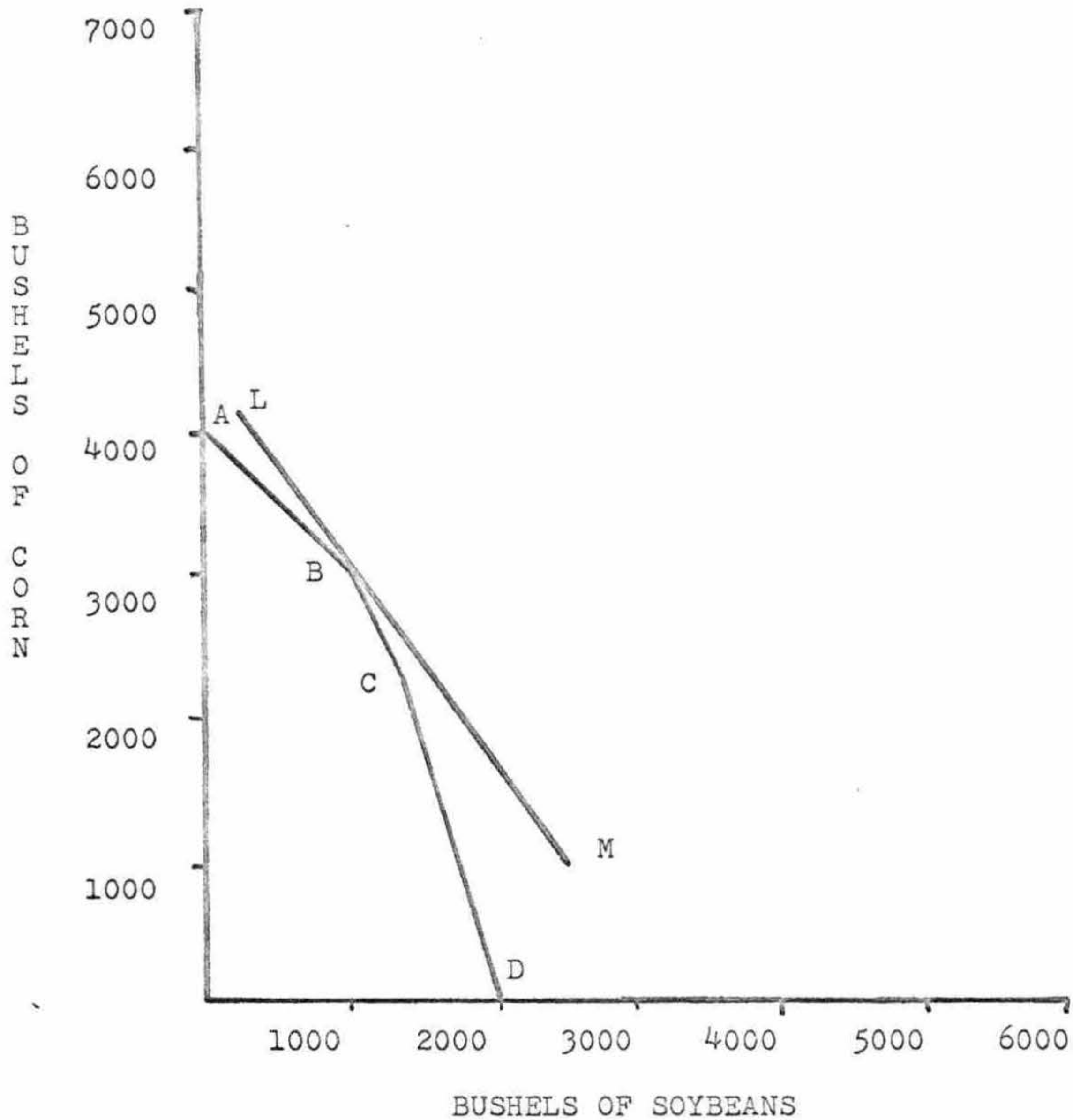

Figure 7. Determination of production three input case

crop rotation activity where the growing of alfalfa influences the subsequent yield of corn.

Divisibility

It is assumed in linear programming that inputs and products are infinitely divisible. Or that they can be used and produced in fractional units. For example, a solution may call for an input of 43.6 hours of labor and an output of 21.3 acres of corn. This is admissible since labor and acres can be divided as such. The same solution may, however, call for the production of 36.7 head of beef cows. This type of solution occurs quite frequently. The programmer must round the answer to the nearest integer value, in this case 37.

Finiteness

The assumption of finiteness is what makes linear programming possible and feasible. It is assumed that the number of alternative activities has a limit. If there were no limit the programmer would never complete his task of defining and developing coefficients. A solution would never be accomplished. There also is a definable limit on the quantity of inputs available for production.

Interpretation of solutions

There are two aspects of a linear program solution of a farm planning problem which are of interest to those involved with the process. Of primary importance is the actual solution to the problem showing the quantities of each enterprise which should be produced to maximize income within the restraints prices, input-output coefficients assumed. The second important item is the shadow prices which are indicated by the solution.

Shadow prices are the positive z-c values found on the disposal activities in a final feasible and optimum solution. These numbers indicate that if one more unit of the resource in question were put in disposal (disuse) the value of the solution would be decreased by the amount of the shadow price. Conversly a one unit increase in a restricted resource would increase the value of the solution by the same amount. Hence, the shadow prices indicate the marginal value product of the resources. If the shadow price of a resource is greater than the price of the resource the farm planner may elect to purchase more units of the resource until the point is reached where its marginal value product is equated with its price. This is the point of maximum net profit.

THE METHOD OF DEFINING THE FIELD OPERATION TIME RESTRICTION

Shaw (7) has developed a method of estimating the number of days suitable for field operation by an analysis of weather data. The method consists of using the following five types of weather information: (1) high daily temperatures (2) low daily temperatures (3) total amount of rainfall during the twenty-four hour day (4) the amount of rainfall which fell the previous night and (5) the degree of cloud cover during the daylight hours. Weather data was obtained from the United States Weather Bureau consisting of observations from Omaha, Nebraska Weather Station, from the years 1915 through 1966.[5] The five weather characteristics mentioned previously were obtained from weather records and transcribed on to data cards for use in a computer analysis program. This data spanned the months April through November.

The next step was to establish the parameters of the analysis of the weather data aimed at estimating the number of field operation days during the crop growing season. The first parameter to be considered was the freezing of the soil. The soil was considered frozen after (a) a minimum air temperature of less than 20° F. was recorded or (b) both maximum and minimum air temperatures were less than 32° F. for two consecutive

[5] The data for 1949 was unuseable due to a change in method of reporting for that year.

days. The soil was considered to remain frozen until (a) maximum and minimum air temperatures greater than 32^{o} F. for two consecutive days (b) maximum air temperature greater than or equal to 70^{o} F. (c) maximum air temperature greater than 60^{o} F. and minimum air temperatures greater than 32^{o} F. or (d) maximum and minimum air temperatures both greater than 32^{o} F. or more than 0.5 inch of rain fell. The freezing and thawing process of the soil could be repeated several times during the spring season.

After consultation with Phillips[6] the following soil moisture parameters were defined. Only the top six inches of soil was to be considered in the computation of the field operation time restriction. This layer was assumed to hold a maximum of 1.3 inches of available water except early in the season when the soils were cold. It was assumed this layer would hold an additional 0.5 inch after thawing until (a) a maximum air temperature of greater than 70^{o} F. was recorded or (b) a maximum air temperature of greater than 65^{o} F. was recorded for three consecutive days. When these conditions occured any excess water over 1.3 inch was perculated to deeper depths. Soil moisture on the date the soil thawed in the

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[6]Phillips, Joseph, Extension Agronomist, Iowa State University, Ames, Iowa. Soil condition for field operation. Personal consultation. 1966

spring was started at 1.8 inches in the top six inches.[7]

The soil was assumed workable when the available soil moisture was .09 inch or less in the top six inches and the soil was no longer frozen. When the soil was frozen precipitation was accumulated and 25 per cent of this total was assumed to enter the soil upon thawing. Any excess over the field capacity values previously discussed either penetrated to deeper depths or ran off on the day of thawing. Rainfall which fell after the thawing of the soil was assumed to enter the soil and accumulate up to the field capacity amounts. Any excess water was assumed to run off.

After rain had fallen it was necessary to define the conditions under which the soil could not be worked even with soil moisture less than 0.9 inch.

Up to May 1 it was assumed that rain during the day of 0.2 inch or more stopped work for the rest of that day regardless of weather conditions. After May 1 0.3 inch or more rain was required to stop work.

With the rain during the night working conditions depended on the amount of rain and the level of soil moisture present. If soil moisture was less than or equal to 0.2 inch on the prior day work could be conducted if (a) skies were clear and rain

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[7]This may not be an accurate assumption but was as close as the data would allow. It can, however, be noted that Shaw (7) obtained a correlation between the observed and predicted number of days available for field operation ranged from .86 to .93 depending upon the month of observation.

was less than or equal to 0.5 inch (b) skies were partly cloudy and rain was less than or equal to 0.4 inch or (c) skies were cloudy and rain amounts were less than or equal to 0.3 inch.

No evaporation was assumed to occur from the soil when frozen. When thawed drying occured on certain days defined as drying days. Conditions necessary for a drying day were (a) minimum air temperature greater than 32° F. maximum air temperature greater than or equal to 50° F. or (b) maximum air temperature greater than or equal to 70° F. with any minimum air temperature. Evaporation was assumed to be greater the first day after rain and evaporation was allowed to continue at a constant rate from the second day after rain until the soil is at zero amount of available moisture. The evaporation rates used are given in Table 1.

Three levels of cloud conditions were assumed to be significant. A clear sky was defined as averaging 0.3 or less of the sky covered with clouds during the day. A partly cloudy sky was defined as one in which from 0.4 to 0.7 of the sky was covered with clouds. A cloudy sky had 0.8 or more of the sky covered with clouds.

The growing season was divided into five periods: Period I extending from March 1 through April 20 is the season devoted primarily to plowing and soil preparation activities; Period II covering April 21 through May 20 is the principal planting season; Period III from May 21 through June 30 is

Table 1. Evaporation in inches per day[a]

	Clear days		Partly cloudy days		Cloudy days	
	Quantity of evaporation	Statement number[b]	Quantity of evaporation	Statement number[b]	Quantity of evaporation	Statement number[b]
(a) All drying days except as listed under (b).						
Up to May 1	0.12	104	0.08	114	0.05	94
After May 1	0.15	99	0.10	109	0.05	94
(b) First drying day after rain.						
Up to May 1	0.17	102	0.13	112	0.05	94
After May 1	0.20	97	0.15	107	0.05	94

[a]Taken from Shaw (7).

[b]Indicates statement number in weather analysis where the evaporation parameter is found.

the cultivating season; Period IV from July 1 to September 30 is the growing season; and Period V extending from October 1 to November 30 is the harvesting season.[8]

The method described above was programmed for computer analysis. The computer program is given in the Appendix.

Explanation of the Computer Program

The weather analysis program developed for this study, although originally designed for weather data from the Omaha Weather Station, with proper substitutions can be used for any locality for which appropriate data is available. A brief explanation of the program which is printed in full in the Appendix is given below and the locations of possible alterations to allow the analysis to be used in other localities is also presented. The statement numbers are given by a format such as "S.0001." For example this will be referred to subsequently as Statement 1.

Statement 1 sets aside in storage 250 spaces for each of the five weather characteristics required by the program for each day. Two hundred forty-three days were considered from each year, April 1 to November 30. In addition, 250 spaces are reserved for each of two "count" variables. Variable KNTA places in storage the numbers of all whole days which are available for field operations.

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[8]These periods will be called by the numbers, for example, Period I, Period II, etc., in the balance of this thesis.

Statements 2 and 3 set up the headings for the print-out page. Statement 4 indicates the number of years which will be considered--in this case 25.

Statements 5 through 12 are used to zero the arrays which were set aside in storage to assure that there are no unwanted numbers remaining from a previous year's data. Statements 13 through 23 provide for the daily weather data to be read and stored for use later in the program. The data is read from cards which contain three days data per card. (Eighty-one cards were needed for each year to read in data for 243 days.)

Statements 24 through 28 set five count variables equal to zero. These are used to count the number of available working days in each of the five periods. Statement 29 sets a total working day variable equal to zero. Statements 31 through 33 zero other variables necessary to the program. Statement 34 sets the amount of soil moisture at 1.8 inches in the top six inches of soil at the time of the first thaw.

Statements 35 through 77 constitute a sift routine to determine if the soil is thawed and if the soil moisture is low enough to permit work in the field. Statements 61 and 62 set the soil moisture maximum at 1.8 inches assuming that any rainfall greater than this amount will either run-off or leach downward. Once the air temperature reaches 70° for one day or 65° for three consecutive days this amount of soil moisture was reduced to 1.3 inches in the top six inches of soil.

Statements 64 and 65 provide for this.

Statements 66 through 75 consider the rainfall for the day in question. Statement 67 states that, if more than 0.3 inch of rain falls for the 24-hour day prior to May 1, soil moisture condition will not permit field work. Statement 68 indicates that 0.2 inch of rain after May 1 will stop field work. Statement 72 provides that with soil moisture of less than or equal to 0.2 inch prior to a nighttime rain equal to or less than 0.5 inch and clear skies the next day field work can proceed. Statement 73 is similar but for nighttime rain equal to or less that 0.4 inch and partly cloudy skies. Statement 74 is for nighttime rainfall equal to or less than 0.3 inch and cloudy skies.

Statements 76, 87, and 119 provide for the adding of rainfall to soil moisture. Statements 77 and 81 provide for soil moisture to increase to 0.9 inch before stopping field work. This measure would vary with soil types and topography.

Statements 78 through 80 provide for full working days to be counted. Statements 82 through 84 count half working days.

Statements 86 through 120 allow for evaporation of moisture from the soil. Evaporation varies with the cloud cover, time of year, and length of time after rainfall. See Table 1.

The rate of evaporation would vary with soil types and latitude of the location.

Statement 117 allows for one-fourth of the moisture to be retained by the soil before thawing. Statements 121 and 122 keep the soil moisture variable from becoming less than zero.

Statements 124 through 146 count and place in the proper season the full working days which were placed in a storage array previously. Statements 130 through 176 indicate the print-out format and end the program.

<u>Converting the weather program to other localities</u>

The weather analysis program can be used for other localities by certain discrete changes which will be reviewed here.

(1) In statement 1 arrays should be set aside to allow storage for at least as many days per year as are to be considered.

(2) The number of years to be considered should be placed in columns 18 and 19 of statement 4.

(3) The number of cards to be read for one year's data must be placed in columns 18 and 19 of statement 17.

(4) The amount of moisture (in inches) the soil will hold in the top six inches when saturated prior to May 1 must be placed in columns 13, 14, and 15 of statement 33, in columns 16, 17, and 18 of statement 61, and columns 12, 13, and 14 of statement 62.

(5) The number of days to be considered for each year is placed in columns 19, 20, and 21 of statement 35.

(6) The amount of moisture (in inches) the soil will hold in the top six inches when saturated after May 1 is placed in columns 17, 18, and 19 of statement 64 and in columns 13, 14, and 15 of statement 65.

(7) The amount of rainfall which will stop field work regardless of soil moisture conditions is placed in columns 20 and 21 of statement 67 for days prior to May 1 and in columns 20 and 21 of statement 68 for May 1 and the days following.

(8) The amount of nighttime rainfall which will preclude field work the next day is placed in columns 21 and 22 of statement 72 for days with clear skies, statement 73 for days with partly cloudy skies, and statement 74 for days with cloudy skies.

(9) The inches of moisture in the top six inches of soil which will result in unworkable soil conditions is placed in columns 17, 18, and 19 of statement 77 and also in columns 17, 18, and 19 of statement 81.

(10) Statements 94 through 115 contain the amounts of evaporation which occur. Changes must be made here to correct for soil types and latitude, see Table 1.

(11) Statements 131 through 134 permit defining various restraint periods during the year. These definitions can be changed by counting from the first day considered in the weather program and making changes in columns 15, 16 and 17 of these statements. Statements 154 through 157 are similar and require the same changes.

DEFINING THE FIELD OPERATION RESTRICTION

Statistical Analysis of Data

The data obtained from the weather analysis program was in the form of a listing of the number of days suitable for field operation for each of the five seasons during the 50 years analyzed. This data was then plotted on a distribution graph and was fitted to a known distribution. A chi-square test was made to test the data of each season for goodness of fit to a known distribution. This test is shown in Table 2 with the standard deviation, and the known distribution to which the data fit with the lowest chi-square value.

Table 2. Distributions of days suitable for field operations by restraint periods

Period	Restraint period	Distribution type	Chi-square value	Mean number of days	Standard deviation
I	Plowing	Normal, one tailed	21.2	2.22	3.39
II	Planting	Even	7.4	11.76	7.56
III	Cultivation	Normal	22.9	18.48	8.0
IV	Growing	Even	10.0	51.29	13.6
V	Harvest	Normal	33.3	23.75	7.6

After the distributions were determined the number of field operation days were estimated with a given probability of occurrence.[9] In this thesis we seek to determine how many days are available for field operation if the operator wants to achieve timely field operations a given percentage of years, for example, six years out of ten. Estimates of the number of field operation days during each of the five restraint periods and their probability of occurrence with a 95 per cent confidence interval are given in Table 3.

Table 3. Days suitable for field operations and probability of occurrences

Period	Probability of occurrence				
	.5	.6	.7	.8	.9
I	4.58	3.58	2.62	1.90	.88
II	11.76	9.60	7.20	4.80	2.40
III	18.48	16.85	14.68	12.14	6.19
IV	52.00	47.20	42.40	37.60	32.80
V	23.75	22.18	20.13	17.73	12.08
Totals	108.28	97.62	85.72	73.12	53.91

Conversion of data to an hourly basis

The time available for field operation is given in Table 3 in days per restraint period. In most planning models time coefficients are given in hours. Time restraints in terms of hours are shown in Table 4. The conversion was accomplished by multiplying the field operation days by the average number

[9] The reverse could also be estimated, for example, the probability of having a given number of field operation days. This was not of interest in this thesis however.

of daylight hours per day in the seasonal period. The average hours of daylight was found in an almanac (11).

Table 4. Estimated hours of field operation time during five restraint periods

Period	Average hours of daylight per day	Probability of occurrence .5	.6	.7	.8	.9
I	12.25	56.11	43.86	32.10	23.28	10.78
II	14.22	167.23	136.51	102.38	68.26	34.13
III	15.29	282.56	257.63	224.46	185.62	94.65
IV	13.41	696.32	632.95	568.58	504.22	439.48
V	10.04	238.45	222.69	202.11	178.11	121.28

Application of the Time Restraints to a Linear Programming Model

A linear programming model designed to incorporate the use of field time restraints preveiously defined is presented in Table 5. Examples of activities are given and coefficients are presented for purposes of illustration.

Explanation of B column entries

Two basic types of entries in the B column are included in the model shown in Table 5. These are transfer rows and maximum restraints.[10] Transfer rows are similar in appearance to restrictions. A transfer row provides a means whereby output or services of one activity may be transferred to

[10] Two additional types of B column entries are also common in a linear programming model but are not used in this model. These are minimum restraints and equality restraints.

Table 5. Linear programming model

R01 Plowing and soil preparation transfer row.

R02 Planting transfer row.

R03 through R07 Field operation time restraints for seasonal periods.

R08 through R13 Total time restraints for seasonal periods.

R14 Grain transfer row.

R15 Hay transfer row.

R16 Capital restraint row.

R17 Land restraint row.

P01 Spring soil preparation with a three bottom plow and associated machines.

P02 Spring soil preparation with a four bottom plow and associated machines.

P03 Fall plowing with a four bottom plow and associated machines.

P04 Planting activity.

P05 Corn growing activity.

P06 Soybean growing activity.

P07 Four year rotation activity (corn, corn, oats and alfalfa).

P08 Livestock activity.

P09 through P13 Labor hiring activities during the cropping season divided by seasonal periods.

P14 Labor hiring activities during the winter season.

Table 5. Linear programming model

	B	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14
R01	0	-1	-1	-1	1	0	0	0	0	0	0	0	0	0	0
R02	0	0	0	0	-1	1	1	2	0	0	0	0	0	0	0
R03	32	.33	.25	.08	0	0	0	.5	0	-1	0	0	0	0	0
R04	102	0	0	0	.2	.01	.01	.1	0	0	-1	0	0	0	0
R05	224	0	0	0	0	.5	.8	1.8	0	0	0	-1	0	0	0
R06	569	0	0	0	0	.3	.7	1.3	0	0	0	0	-1	0	0
R07	202	0	0	.20	0	.8	.6	1.7	0	0	0	0	0	-1	0
R08	140	.33	.25	.08	0	.01	.01	.7	1	-1	0	0	0	0	0
R09	174	0	0	0	.2	.01	.01	.1	2	0	-1	0	0	0	0
R10	259	0	0	0	0	.5	.8	1.8	1	0	0	-1	0	0	0
R11	319	0	0	0	0	.3	.7	1.3	1	0	0	0	-1	0	0
R12	280	0	0	.20	0	.8	.6	1.7	3	0	0	0	0	-1	0
R13	226	0	0	0	0	.05	.05	.1	5	0	0	0	0	0	-1
R14	0	0	0	0	0	-95	0	-210	45	0	0	0	0	0	0
R15	0	0	0	0	0	0	0	-3	2	0	0	0	0	0	0
R16	30000	2	1.7	1.9	.8	45	-40	150	200	1.5	1.5	1.5	1.5	1.5	1.5
R17	300	1	1	1	0	0	0	2	0	0	0	0	0	0	0
Activity maximum	0	96	128	0	510	0	0	0	0	100	125	200	400	100	300

another activity within the model. In the model presented in Table 5, for example, land plowed and prepared for planting may be transferred to a crop growing activity. Transfer rows normally have zero coefficients in the B column, however, this need not be the case.

Rows numbered R01, R02, R14, and R15 are transfer rows in the model in Table 5. R01 is a plowing and soil preparation transfer row which allows for land to be prepared for planting by several combinations and methods of field equipment. R02 defines a planting transfer row which provides for land previously plowed and prepared for planting to be planted and transferred to the crop activities.

R14 is a grain transfer row and R15 a hay transfer row. These allow for grain and hay to be produced by several activities and used as inputs for other activities.

The balance of the entries in the B column are maximum restraints in this model. Maximum restraints set upper limits on the quantities of resources available for use in the farm business.

Entries R03 through R07 define the field operation time restraints for the various seasons as below.

R03 plowing season field operation time restraint.

R04 planting season field operation time restraint.

R05 cultivating season field operation time restraint.

R06 growing season field operation time restraint.

R07 harvest season field operation time restraint.

The B column coefficients were taken from Table 4 with the probability of occurrence of these restraints being .7. Thus the operator will have at least the stated number of hours for field operation. Seventy per cent of the time or seven years out of ten.[11]

Entries R08 through R13 define total time restrictions by seasons. This indicates the total amount of time available for productive farm work and consists of the total waking hours minus time consumed in non-productive activities such as meals, record keeping, travel between parcels of land, etc.

The total time available for productive farm work was estimated through the use of time reporting sheets. The owner-operator of the farm in Monona County previously mentioned was asked to record each evening the amount of time spent that day on each enterprise presently on the farm. Records were kept on the allocation of both the owner's and the hired man's time. From this time study the total hours of productive work time used on each enterprise was estimated.

It was determined that the amount of time spent in working directly with the livestock and crop enterprises was 62.6 per cent of the total time available for the year.

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[11]The choice of the .7 probability level has an arbitrary choice. There is no reason why the risk preference cannot vary with the season. For example, .7 for the planting season but .9 probability for the harvest season. This is a risk preference judgment which must be defined by the farm planner before use of this data.

The balance of time was used for overhead activities not directly allocatable to any one enterprise. The percentage of time used in productive work varied to a large extent with the season of the year as is shown in Table 6.

Table 6. Per cent of total time allocatable to specific crop and livestock activities

Time period	Total time available in hours	Hours of time used in productive work	Percentage of time used in productive work
Dec., Jan., Feb.	1080	450	42
March 1-Apr. 20	620	310	50
Apr. 21-May 20	490	375	76
May 21-June 30	690	542	79
July 1-Sept. 30	1180	702	60
Oct. 1-Nov. 30	860	649	75

In the linear programming model in Table 5 the total available time was reduced by the percentages given in Table 6. Only the owner's time was entered in the B column since labor hiring activities are included in the model. The total labor time restrictions are shown in Table 7.

R16 defines a capital restraint and is shown with a entry of $30,000 in the B column. R17 defines a land restraint with a B column value of 300 units.

It can be noted that in certain seasonal periods the total time restraint is more restricting than the field operation time restraint. Note the two restraints for the growing season. The total time restraint, R11, is 319 hours and the field operation time restraint, R06, is 569 hours. This is the normal time for farmers to take vacations so this difference is easily explained.

Table 7. Total labor time restrictions

Time period	Owner's time	Hired man's time
Dec., Jan., Feb.	226 hrs.	270 hrs.
Mar. 1-Apr. 20	140	170
Apr. 21-May 20	174	196
May 21-June 30	259	294
July 1-Sept. 30	319	390
Oct. 1-Nov. 30	280	368

An activity maximum restraint is placed on several activities. This allows the activity to increase up to but not beyond this maximum.

The activity maximum is of two types. First, a maximum number of hours of hired labor is set for various seasons of the year. This maximum results from a subjective evaluation of the labor market and a determination of the maximum number of hours available for hire within the specific time period.

Secondly, an activity maximum is needed on the soil preparation and planting activities to prevent the inclusion in the solution of more units of these activities than are feasible. For example, every unit of labor hired for the planting season will increase the B column restriction for planting season field operation time by one unit. This, however, does not allow the planting activity to increase since a single machine cannot increase its productivity or use by an increase in labor supply. The amount of land planted is a function of the number of hours of field operation time given that a sufficient amount of labor is available.

The activity maximum restraint therefore is determined by the smallest ratio of labor restraint divided by the activity coefficient for that resource. For example, with the planting activity the B column entry for planting season field operator time is 102 units and the planting activity, P04, coefficient for field operator time during the planting season is .2. The ratio is $\frac{102}{.2} = 510$, units of P04 can be accomplished regardless of hired labor supply.

Maximums are also placed in P01, a soil preparation activity using a three bottom plow and associated machines, and P02, a soil preparation activity consisting of a four bottom plow and associated machines. The most restricting ratios are $\frac{32}{.33} = 96$ and $\frac{32}{.25} = 128$ respectively.

Explanation of activities

Two types of activities are presented in the model in Table 5. First, production activities are those which use resources to produce some product. Secondly, are labor hiring activities which hire labor for specific seasons and add the labor quantity to the original restraint in the B column.

P01, P02, P03 are soil preparation activities to plow and prepare the soil for planting. These three activities differ as follows:

P01. A three bottom plow and associated machines with plowing done in the spring.

P02. A four bottom plow and associated machines with plowing done in the spring.

P03. A four bottom plow and associated machines with plowing done in the fall and other soil preparation operation accomplished in the spring.

Each soil preparation activity has a unique set of input coefficients. One unit of land is required and one unit of land prepared for planting is forthcoming. P01 requires a greater amount of labor input during the spring plowing season than does P02. P03 requires a significant portion of its labor requirement during the harvest season.

For cropping activities time is required from both the seasonal field operation time restraint and also from the seasonal total time restraint since time consumed by field operations cannot be used by other productive activities. The soil preparation activities may increase up to the activity maximum discussed previously.

Labor time is required from both the seasonal field operation time restraint and also from the seasonal total time restraint since time consumed by field operations cannot be used by other productive activities. The soil preparation activities may increase up to the activity maximum discussed previously.

A planting activity is defined requiring an input of one unit of plowed and prepared land from the soil preparation transfer row and placing one unit of planted land into the planting transfer row. The planting activity requires inputs of labor from the planting season field time restraint and from the total planting season time restraint. Planting may increase up to 510 units since only one planting machine is used.

Two single crop activities are shown, corn and soybeans. Each requires inputs of one unit of planted land, labor inputs in the planting, cultivation, growing, and harvest season field time restraints and total time restraints. The corn activity adds 95 units of grain to the grain transfer row and requires 45 units of capital. The soybean activity adds no grain to the grain transfer row but adds 40 units to the capital row under the assumption that the soybeans produced are sold and the net over costs added to the capital supply.

A four year crop rotation is also indicated showing two years of corn followed by a year of oats and a year of meadow. This activity requires an input of two units of planted land, labor inputs from all seasons, and a capital input of 150 units. Grain is added to the grain transfer row in the amount of 210 units and three units of hay is added to the hay transfer row.

It can be noted that in some instances the total time coefficient is greater in value than the field operation time coefficient for the same seasonal period. This can be explained by time consuming events which do not require field operation time. Examples of these are seed and fertilizer purchasing and adjustments of machines etc.

One livestock activity is illustrated showing labor inputs from the total time restraints only. A grain input of 45 units, hay input of 2 units, and a capital requirement of 200 units.

Six labor hiring activities are shown each contributing one unit of labor to a particular seasonal period. For example the plowing season labor hiring activity adds one unit of labor to the plowing season field restraint and adds one unit of labor to the total plowing season labor restraint. Each unit hired requires a capital payment of 1.50 units and may increase up to the activity maximum which indicates the total amount of labor available at the set price during the various seasonal periods.

SUMMARY

Accurate time restraints are very important in linear programming for farm planning. The accuracy of the solutions to farm planning problems is dependent on defining the restraints with confidence.

Fifty years of weather data from the Omaha, Nebraska Weather Station consisting of (1) high daily temperature (2) low daily temperature (3) total daily rainfall (4) nighttime rainfall and (5) cloud cover conditions was considered for each of a 243 day growing season per year. A weather analysis program was developed to analyze this data to determine the number of days available to the farm operator for field operations in each of five seasonal periods per year. These five seasonal periods were I plowing season II planting season III cultivation season IV growing season and V harvest season.

This data was then fit to a known distribution using a chi-square goodness of fit test. It was found that the number of field operation days fit a normal distribution for the cultivation and harvest seasons. The planting and growing seasons fit a even distribution and the plowing season fit a normal one tailed distribution. After the distribution was determined the probabilities of occurrence could be ascertained. This consisted of the number of days available for field operations per seasonal period with given probabilities of occurrence.

It should be stressed that the purpose of this thesis was to develop the method of determining field operation days and the data presented must be considered as illustrative only.

Total time restraints were determined by the use of labor accounting sheets on a sample farm. With this data the proportion of total time used in productive activities was ascertained.

A linear programming model was then introduced indicating how these newly defined time restraints could be used to make the solutions more accurate and meaningful. Both total time restraints for the six seasonal periods and field operation time restraints for five seasonal periods of the growing season were included in the model.

An area of possible further study in this area might be suggested. It would mean very much to farm planners and programmers if these accurate restraints could be determined for all areas of the state. The weather analysis program included requires weather data which is kept at only first order weather stations. This limits somewhat the number of areas which this type of analysis can be accomplished, however, any increase in the amount of planning information would be a help in farm planning.

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APPENDIX

```
ISU DISK RES SPOOLED BPS FORTRAN

/JOB                    U0843 N. PATRICK                                        %%%
/FTC
BEGIN COMPILATION
 S.0001           DIMENSION MTEMP(250),LTEMP(250),RAIN(250),RAINN(250),KLOUD(250),
                 1KNTA(250),KNTB(250)
 S.0002           WRITE (3,1)
 S.0003         1 FORMAT(1H1,10X,4HYEAR,6X,8HPERIOD 1,6X,8HPERIOD 2,6X,8HPERIOD 3,
                 16X,8HPERIOD 4,6X,8HPERIOD 5,6X,5HTOTAL)
 S.0004           DO 180 M=1,25
 S.0005           DO 150 N=1,250
 S.0006           MTEMP(N)=0.0
 S.0007           LTEMP(N)=0.0
 S.0008           RAIN(N)=0.0
 S.0009           RAINN(N)=0.0
 S.0010           KLOUD(N)=0.0
 S.0011           KNTA(N)=0.0
 S.0012           KNTB(N)=0.0
 S.0013       150 CONTINUE
 S.0014           IA=1
 S.0015           IB=2
 S.0016           IC=3
 S.0017           DO 175 L=1,81
 S.0018           READ (1,170)I,MTEMP(IA),LTEMP(IA),RAIN(IA),RAINN(IA),KLOUD(IA),
                 1I,MTEMP(IB),LTEMP(IB),RAIN(IB),RAINN(IB),KLOUD(IB),
                 2I,MTEMP(IC),LTEMP(IC),RAIN(IC),RAINN(IC),KLOUD(IC)
 S.0019       170 FORMAT(I3,2I3,2F5.2,I2,I3,2I3,2F5.2,I2,I3,2I3,2F5.2,I2)
 S.0020           IA=IA+3
 S.0021           IB=IB+3
 S.0022           IC=IC+3
 S.0023       175 CONTINUE
 S.0024           CTI=0.0
 S.0025           CTII=0.0
 S.0026           CTIII=0.0
 S.0027           CTIV=0.0
```

Printout 1. Weather analysis program

```
      CTV=0.0
      TOTAL=0.0
      KOUNT=0.0
      JK=0.0
      IJ=0.0
      TRAIN=0.0
      SMST=1.8
      DO 110 I=1,243
      TRAIN=TRAIN+RAIN(I)
      KLCOD=KLOUD(I)
      J=I-1
      K=I-2
      IF(LTEMP(I)-20) 90,90,2
    2 IF (MTEMP(I)-60)4,3,3
    3 IF (LTEMP(I)-32)4,4,19
    4 IF (MTEMP(I)-70)5,19,19
    5 IF (LTEMP(I)-32)6,6,9
    6 IF (MTEMP(I)-32)7,7,9
    7 IF (MTEMP(J)-32)8,8,9
    8 IF (LTEMP(J)-32)90,90,9
    9 IF (LTEMP(I)-32)13,13,10
   10 IF (MTEMP(I)-32)13,13,11
   11 IF (LTEMP(J)-32)13,13,12
   12 IF (MTEMP(J)-32)13,13,19
   13 IF (MTEMP(I)-32)16,16,14
   14 IF (LTEMP(I)-30)16,16,15
   15 IF (RAIN(I)-.5) 16,19,19
   16 IF (MTEMP(I)-50)90,17,17
   17 IF (RAIN(I)-.5) 90,19,19
   19 IF (MTEMP(I)-70)20,20,25
   20 IF (MTEMP(I)-65)23,23,21
   21 IF (MTEMP(J)-65)23,23,22
   22 IF (MTEMP(K)-65)23,23,25
   23 IF (SMST-1.8)27 ,27,24
   24 SMST=1.8
```

Printout 1 continued

```
      GO TO 27
   25 IF (SMST-1.3)27,27,26
   26 SMST=1.3
   27 IF (I-30)29,28,28
   28 IF (RAIN(I)-.3)30,99,99
   29 IF (RAIN(I)-.2)30,99,99
   30 IF (RAINN(I))32,31,32
   31 IF (KOUNT-J)47,37,47
   32 GO TO (33,34,35),KLCOD
   33 IF (RAINN(I)-.5)36,36,61
   34 IF (RAINN(I)-.4)36,36,61
   35 IF (RAINN(I)-.3)36,36,61
   36 IF (SMST-.2)37,61,61
   37 SMST=SMST+RAIN(I)
      IF (SMST-.90)38,38,62
   38 JK=JK+1
      KNTA(JK)=I
      GO TO 60
   47 IF (SMST-.90)48,48,62
   48 IJ=IJ+1
      KNTB(IJ)=I
      GO TO 60
   60 KOUNT=I
      GO TO 62
   61 SMST=SMST+RAIN(I)
   62 IF (LTEMP(I)-32)64,64,63
   63 IF (MTEMP(I)-50)110,65,65
   64 IF (MTEMP(I)-70)110,65,65
   65 GO TO (66,68,70),KLCOD
   66 IF (I-30)74,71,71
   68 IF (I-30)80,77,77
   70 SMST=SMST-.05
      GO TO 100
   71 IF (RAIN(J))72,73,72
   72 SMST=SMST-.2
      GO TO 100
```

Printout 1 continued

```
   73 SMST=SMST-.15
      GO TO 100
   74 IF (RAIN(J))75,76,75
   75 SMST=SMST-.17
      GO TO 100
   76 SMST=SMST-.12
      GO TO 100
   77 IF (RAIN(J))78,79,78
   78 SMST=SMST-.15
      GO TO 100
   79 SMST=SMST-.10
      GO TO 100
   80 IF (RAIN(J))81,82,81
   81 SMST=SMST-.13
      GO TO 100
   82 SMST=SMST-.08
      GO TO 100
   90 IF(RAIN)110,110,91
   91 SMST =SMST+RAIN/4.0
      GO TO 110
   99 SMST=SMST+RAIN(I)
      GO TO 110
  100 IF(SMST)105,110,110
  105 SMST=0.0
  110 CONTINUE
      JN=1
      KN=1
      DO 131 IJK=1,35
      DO 130 IN=1,7
      IF (KN-KNTA(JN))128,111,128
  111 JN=JN+1
      IF (IN-7)112,128,112
  112 IF (KN-20)117,117,113
  113 IF (KN-50)118,118,114
  114 IF (KN-91)119,119,115
```

Printout 1 continued

```
  115 IF (KN-182)120,120,121
  117 CTI=CTI+1.0
      GO TO 128
  118 CTII=CTII+1.0
      GO TO 128
  119 CTIII=CTIII+1.0
      GO TO 128
  120 CTIV=CTIV+1.0
      GO TO 128
  121 CTV=CTV+1.0
  128 KN=KN+1
  130 CONTINUE
  131 CONTINUE
      JM=1
      KM=1
      DO 161 IKJ=1,35
      DO 160 IM=1,7
      IF (KM-KNTB(JM))158,141,158
  141 JM=JM+1
      IF (IM-7)142,158,142
  142 IF (KM-20)147,147,143
  143 IF (KM-50)148,148,144
  144 IF (KM-91)149,149,145
  145 IF (KM-182)151,151,152
  147 CTI=CTI+.5
      GO TO 158
  148 CTII=CTII+.5
      GO TO 158
  149 CTIII=CTIII+.5
      GO TO 158
  151 CTIV=CTIV+.5
      GO TO 158
  152 CTV=CTV+.5
  158 KM=KM+1
  160 CONTINUE
  161 CONTINUE
```

Printout 1 continued

```
      TOTAL=CTI+CTII+CTIII+CTIV+CTV
      WRITE (3,165)M,CTI,CTII,CTIII,CTIV,CTV,TOTAL,TRAIN
  165 FORMAT(1H0,10X,I3,7F14.1)
  180 CONTINUE
      END
```

Printout 1 continued